

**VERTICAL DISPLACEMENT MEASUREMENTS IN CENTRAL CALIFORNIA
WITH A LONG-BASELINE TWO-FLUID TILTMETER**

Howard C. Merchant

**Department of Mechanical Engineering
University of Washington FU-10
Seattle, Washington 98195**

**USGS CONTRACT NO. 14-08-0001-18224
Supported by the EARTHQUAKE HAZARD'S REDUCTION PROGRAM**

OPEN-FILE NO. 81-885

**U.S. Geological Survey
OPEN FILE REPORT**

This report was prepared under contract to the U.S. Geological Survey and has not been reviewed for conformity with USGS editorial standards and stratigraphic nomenclature. Opinions and conclusions expressed herein do not necessarily represent those of the USGS. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

Summary: Final Report

Contract No. 14-08-0001-18224

April 17, 1981

VERTICAL DISPLACEMENT MEASUREMENTS IN CENTRAL CALIFORNIA
WITH A LONG-BASELINE TWO-FLUID TILTMETER

Howard C. Merchant
Department of Mechanical Engineering
University of Washington FU-10
Seattle, Washington 98195

A two-fluid multiple leg tiltmeter has been assembled and installed at a test sight near San Juan Bautista, California. The system consists of two legs at 75° with lengths of 243 meters and 193 meters. Each leg has two-fluid lines which are both exposed to the same temperature environment, one containing methyl ethyl ketone and one containing N-butyl alcohol. The fluid and tubing sizes were selected using a number of criteria including accuracy for thermal compensation, dynamic response characteristics, safety, and cost. The reservoirs are supported on thermally compensated piers embedded approximately 4 meters.

The dynamic responses of the system measured in the field compare well with theory. The measurement of tilt at the test site for times of geophysical interests will be carried out in a follow-on program.

TABLE OF CONTENTS

	PAGE NO.
Introduction	1
Thermal Compensation	1
Fluids	3
Thermal and Safety Considerations	3
Dynamic Response Considerations	5
Test Site Installation	6
Test Site	6
Pier	7
Response	9
Conclusions and Recommendations	12
References	13
Tables	14
Figures	15 - 27
Appendix A - Fluid Properties Selection	28 - 36
Appendix B - Safety Considerations	37 - 44
Appendix C - Dynamic Response	45 - 54
Appendix D - Thermally Compensated Pier Test	55 - 59
Appendix E - Tilt Computations	60 - 66

LIST OF TABLES

		PAGE NO.
Table 1	Response to an Initial Displacement (Methyl Ethyl Ketone)	14
Table 2	Response to an Initial Displacement (N Butyl-Alcohol)	14

LIST OF FIGURES

Figure 1	Thermal Compensation Schematic	15
Figure 2	Tiltmeter Site	16
Figure 3	Tiltmeter Geometry	17
Figure 4	View Toward Station One	18
Figure 5	View Toward Station Two	19
Figure 6	Joint Protection	20
Figure 7	M.E.K. Layout	21
Figure 8	Alcohol Layout	22
Figure 9	Transducer Locations	23
Figure 10	Compensated Pier	24
Figure 11	Pier Components	25
Figure 12	Station One, Complete	26
Figure 13	Station Two, Complete	27

Introduction

The need for a water-tube tiltmeter and the details of its operation were covered by Eaton [1]* in 1959. Since that time more modern instrumentation has allowed modification and further development beyond the basic single-tube fluid tiltmeter with a mechanical surface sensor. A number of instruments are discussed in connection with thermal errors in a paper by Bevan and Bilham [2] including one due to Huggett, et al. [3]. This particular instrument, the two-fluid tiltmeter, is the subject of this project. A laboratory single leg prototype developed by Terra Technology Corporation [4] was modified and expanded for use in a field test site in central California.

The two major differences in this fluid tiltmeter are the use of two parallel tubes filled with fluids of different thermal properties experiencing the same thermal environment and the design of the level sensors in the reservoirs. The latter being piezoelectric acoustic drivers (sonar type transducers) submerged in the liquid which detect the change in the surface height in the reservoirs.

Thermal Compensation

The use of two fluids with different expansion coefficients allows the elimination of temperature effects assuming the same thermal environments for both fluids over the complete tiltmeter circuit [3,4]. The basic principle can be demonstrated by considering the simple two-tube, two-fluid system shown in Figure 1. Assume there are different fluids in A and B which have a linear variation in density with temperature. Considering fluid Column A first and let

ρ_{AO} = Density at reference temperature,

$\rho_A(T)$ = Density at temperature T,

and

α_A = linear density coefficient.

*Numbers in brackets [] refer to references.

Then

$$\rho_A(T) = \rho_{AO}(1 + \alpha_A T)$$

and the pressure point p (P_p) is (1)

$$P_p = \int_0^{h_1} \rho_A(T) g dx = g \rho_{AO} (h_1 + \alpha_A I_1) \quad (2)$$

$$\text{where } I_1 = \int_0^{h_1} T dx.$$

Also

$$P_p = \int_0^{h_3} \rho_A(T) g dx + \int_{h_3}^{h_2+h_3} \rho_A(T) dx = g \rho_{AO} [(h_2+h_3) + \alpha_A I_{2+3}] \quad (3)$$

$$\text{where } I_{2+3} = \int_0^{h_2+h_3} T dx.$$

Equating (2) and (3)

$$h_1 - h_2 = h_3 + \alpha_A (I_{2+3} - I_1) = \Delta A. \quad (4)$$

Similarly for fluid B

$$H_1 - H_2 = H_3 + \alpha_B (I_{2+3} - I_1) = \Delta B. \quad (5)$$

The terms $I_{2+3} - I_1$ are identical in (4) and (5) if both fluid columns see the same thermal environment. Therefore:

$$(\Delta A - h_3)/\alpha_A = (\Delta B - H_3)/\alpha_B.$$

If the fluid columns are on the same base $H_3 = h_3$ and

$$h_3 = (\Delta A \alpha_B - \Delta B \alpha_A) / (\alpha_B - \alpha_A). \quad (6)$$

Thus by measuring the differences in the fluid heights in the two legs, ΔA and ΔB , and knowing the density (or expansion) coefficients for the two fluids the elevation change between the two stations can be determined without requiring a knowledge of the thermal profile along the fluid columns. The

effect of nonlinearities in the fluid density is discussed below under fluid selection.

Fluids

Thermal and Safety Considerations

In the previous section the ideal operation of the two-fluid system was described using a linear variation in density with temperature for each of the fluids. The density-temperature behavior is actually better described by a polynomial. The coefficients for a quadratic variation with temperature are available for some fluids (5). Using this information the density can be more accurately described as

$$\rho = \rho_0 (1 + \alpha T + \beta T^2). \quad (7)$$

Repeating the analysis in the previous section with the additional term

$$\Delta A = \bar{h}_3 + \alpha_A I + \beta_A J \quad (8)$$

$$\Delta B = \bar{h}_3 + \alpha_B I + \beta_B J \quad (9)$$

$$\text{where } I = I_1 - I_{2+3}$$

$$J = J_1 - J_{2+3}$$

$$\text{and } J_1 = \int_0^{h_1} T^2 dx.$$

The elevation change based on the nonlinear temperature variation is

$$\bar{h}_3 = \Delta A - [(\Delta B - \Delta A)(\alpha_A I + \beta_A J)] / [(\alpha_B - \alpha_A) + (\beta_B - \beta_A)] \quad (10)$$

and is related to the linear result by:

$$h_3 = \bar{h}_3 + J(\alpha_B \beta_A - \alpha_A \beta_B) / (\alpha_A - \alpha_B). \quad (11)$$

J is a function of the unknown temperature variation along the tiltmeter but the last term is eliminated if

$$\alpha_A / \alpha_B = \beta_A / \beta_B \quad (12)$$

with the result that the correct elevation change is given by the linear estimate which is independent of the temperature variation along the fluid line. Therefore the fluids were selected so that α_b and α_a the linear coefficients were well separated to avoid a problem with the denominator in equation (6) but the ratios of the linear quadratic terms were selected to satisfy equation (12) as closely as possible. Other temperature aspects of the fluids considered were freezing and boiling points, viscosity, and the magnitude of the linear expansion coefficient. The minimum operating range (freezing to boiling) was taken as -5°C to 70°C . The viscosity effect is discussed below in connection with the dynamic response. The ratio of the expansion coefficients was controlled by equation (12) but the magnitudes were controlled by the desire to avoid draining or adding fluid to the reservoirs to accommodate seasonal changes. Twenty degrees centigrade was used as the minimum range.

A computer program was written to compare fluid properties and a listing of the program (FLUIDPH) is given in Appendix A. Three hundred and sixty-nine fluid combinations were considered. An excerpt from the output is also shown in Appendix A where melting point (MP), boiling point (BP) and the ratios of the linear coefficients (A) and quadratic coefficients (B) are shown for the two fluids. The error coefficient caused by an inability to exactly satisfy equation (12) is also given. The magnitude of the linear and quadratic coefficients, the reference densities at 0°C , and the viscosity variations as a function of temperature are also given in Appendix A.

Other considerations were cost and safety factors. The fluids selected were methyl ethyl ketone and N-butyl alcohol. Appendix B shows the hygienic guides for the two fluids. NIOSH/MSHA approved respirators

were used when handling the fluids. The description of the respirator used (3M #8712) is also given in Appendix B.

Dynamic Response Considerations

The dynamic response of the two leg tiltmeter was an important design parameter. The response is a function of the tube and reservoir diameters, the tubing length, and the density and the viscosity of the fluid as a function of temperature. The dynamic response for a triangular closed three leg array and a two leg array were discussed in a previous report [6]. A set of coupled second order differential equations, with fluid heights in the reservoirs as dependent variables, result for each leg (fluid) of the tiltmeter. The natural frequencies (eigenvalues) and critical damping ratios for each mode can be computed from the linearized equations. To provide an adequate time constant (time to $1/e$ of the initial disturbance) the damping ratio was kept near the critical value. The equations for dynamic response were programmed to find the natural frequencies, damping ratio and settling time of the tiltmeter as a function of tube diameter, length, and temperature for the fluids selected above.

Appendix C gives a listing of the computer program (DYNAM) and a typical output for the pipe diameters selected. The pipe diameter selected for methyl ethyl ketone was 1.905 cm. (0.75") and N butyl alcohol of 3.175 cm. (1.25").

TEST SITE INSTALLATION

TEST SITE

Background information on the test site selection in the Hollister-San Juan Bautista area was covered in a previous technical report [6]. The final installation site is shown in figure 2. It is located in San Benito County California between Rocks Road and the San Juan lateral on the property owned by L. E. Schumaker* and leased by W. L. Caldera**. The actual geometry of the site is shown in figure 3.

Tubing diameters were 1.9 centimeters (0.75 inches) for the methyl ethyl ketone and 3.2 centimeters (1.25 inches) for the N-butyl alcohol. The lengths of the lines were 243 meters for the North-South leg and 193 meters for the East-West leg. The burial depth was 46 centimeters (18 inches). Figure 4 is a view South along the leg between piers 1 and 2 and figure 5 is a view North along the same leg showing the metal enclosure for pier 2. The tubes were placed side by side at the edge of the trench with the conductors on top. Strain relief covers for the joints in the tubes were made of 6 foot sections of 4 inch diameter PVC pipe cut in half and placed over the joint (Figure 6). Figures 7 and 8 show the valves and tubing layouts for the methyl ethyl ketone and N-butyl alcohol respectively.

The data logger was located at the center pier and the electronics to drive the surface sensing transducers at piers 2 and 1 or 3, depending on the leg being tested. Note that the three reservoir sets are all complete with transducers and connectors but only two driving units are available for the transducers.

One leg was tested at a time linking one to two or three to two. Each reservoir contains both a reference transducer focusing on a surface target and a surface detecting transducer. Therefore, each station contains

* 1145 Fifth Street, P. O. Box 4345, Denver, CO 80204

** 9 Rocks Road, San Juan Bautista, CA 95045

4 transducers, two for each of the fluids, Figure 9. The data logger samples the transducers in pairs so that the reference transducer is always sampled with the associated surface transducer [4,6].

PIER

The bases of the piers were placed at approximately 4.2 meters below the surface to obtain good foundation material and to obtain a stable temperature environment. The piers are compensated for vertical temperature variations by using reentrant concentric tubes of materials with different expansion coefficients. Aluminum and steel were used in the configuration shown in Figure 10.

The inner pipe which extends from the base to the top of the pier is made of steel which has an expansion coefficient of about one half that of aluminum. The center aluminum pipe between the two steel pipes extends from the top of the pier down to within 10.2 cm (4 inches) of the bottom of the footing. The outer steel pipe extends from the bottom of the aluminum pipe to the top of the pier again. The platform is clamped to the outer steel pipe. The combination of the two lengths of steel pipe and the single length of aluminum pipe gives an effective expansion coefficient about 1/21.5 that of a single steel pipe. Change in length (Δ) due to thermal expansion is:

$$\Delta = L\alpha\Delta T \quad (13)$$

Where:

L = Length of tube

α = Expansion coefficient

ΔT = Temperature Change

The total length change in the composite pier is:

$$\Delta_T = (L_{SO} + L_{SI})\alpha_S - L_A\alpha_A \approx 20\alpha_S \text{ cm} \quad (14)$$

since $\alpha_A = 2\alpha_S$

$$L_{SO}^* = L_{SI} = L_A + 10 \text{ cm}$$

*Depends on the table adjustment

Where the subscripts are:

SO = Steel outer cylinder

SI = Steel inner cylinder

S = Steel

A = Aluminum

The length change in an uncompensated steel pier would be

$$\Delta_S = L_{SI} \alpha_S = 430 \alpha_S \text{ cm.}$$

The ratio of compensated to uncompensated expansion of the pier for the configuration in Figure 10 is therefore 1/21.5 as noted above.

The table is carried on a split tube which slides over the outer support tube and is clamped in place by a collar. Lateral stability for the pier is given by the nylon glides between the respective pipes (Figure 10) and support braces cast in concrete attached with turn buckles to the clamping collar for the table. Figure 11 is a photograph of the pier in place with the table, clamping collar, turn buckles and support braces removed. Figure 12 shows pier one complete with the reservoirs, valves and associated tubing installed. The reference target for the height sensing system can be seen in the front bell jar (methyl ethyl ketone). Figure 13 shows pier two, the center pier, with the associated valves and manifolds for allowing single or multiple leg operation of the system.

The pier was tested in the laboratory for temperature compensation by enclosing the pier in an insulated duct and using an electric heater and fan to pass heated air axially along the pier. Thermocouples were used to measure temperature at six places on the three tubes. Dial indicators were used to measure the expansion over the complete, compensated pier and the expansion of the central steel pipe alone for comparison. Heating and cooling rates were too rapid to obtain quasi equilibrium conditions but the data in Appendix D shows that the pier configuration does compensate thermally for the expansion even in a transit condition. The tests were performed the day before the pier was to be transported to

California for installation so the tests could not be repeated at slower heating and cooling rates.

RESPONSE

The system was tested at the site in California by using one leg at a time since only two remote transducer units were available as noted above. All units were operated successfully in pairs. Dynamic response data were taken for comparison with the theoretical predictions. To perturb the system, one reservoir platform was raised with the line valves closed. After equilibrium had been reached, the valve was opened thus putting a displacement step function into the system.

The initial height was obtained by using the data from the logger. Because of the sampling rate limit [6] the time history response was obtained by visually observing the change in the height of the fluid in the reservoirs with scales attached to the bell jars. CB radios were used to coordinate readings taken at both ends of the line for averaging purposes.

The results of the initial tests indicated that there were bubbles trapped in the valves and possibly one of the lines. The valves were purged by cycling fluids back and forth between the reservoirs. During this process two important operational features were noted. First, it is important to have clear tubing, or at least clear tubing sections, near valves or other places where bubbles may be trapped. This makes it possible to observe the effect of the purging process to remove the bubbles. Also, flexing of the pipes or flexible joints must be provided to allow changes in elevation and angle for effective purging of these areas.

Tubing failure was noted over one of the serrated male tube connectors at a valve where the tubes were flexed and rotated. A longitudinal failure in the

tubing occurred where the tubing passes over the serrations rather than at the end of the tube. This indicates that the flexing and rotation of the tubing due to the purging process may have initiated the rupture. Ruptures originating in the pipe, rather than at the end of the pipe, were not observed in laboratory operations with shorter pipe sections where purging problems with valves were not encountered.

After purging, readings were obtained which show excellent correlation with the predicted response. Table 1 gives the results of the response measurements for the methyl ethyl ketone and Table 2 for the N-butyl alcohol. The methyl ethyl ketone line was predicted to be an underdamped system with the result that the height of the reservoir should behave according to the following equation:

$$R = H/H_o = e^{-\rho\omega t} [(\rho/\sqrt{1-\rho^2})\sin(\omega\sqrt{1-\rho^2})t + \cos(\omega\sqrt{1-\rho^2})t], \quad (15)$$

where

H = fluid height relative to the equilibrium position

H_o = the initial height

ω = the undamped natural frequency

ρ = the critical damping ratio.

The predicted values of the parameters are:

$$\omega = (2gA_T/LA_R)^{1/2} = 0.0327 \text{ rad/sec}$$

$$\rho = 4\pi\mu/\omega dA_T = 0.08363 \text{ (dimensionless)}$$

where

g = acceleration of gravity

A_T = area of a tube for the fluid

A_R = area of the reservoir

L = length of fluid tube

d = fluid density

μ = fluid viscosity.

Using these values in the above equation, the fluid heights for the response of the methyl ethyl ketone were predicted and are also shown in Table 1. Note the time constant (time to $1/e$ of the original amplitude) is predicted to be 36.5 seconds.

The N-butyl alcohol line is predicted to be overdamped and therefore, the governing equation is

$$R = H/H_0 = e^{-\rho\omega t} [(\rho/\sqrt{1-\rho^2}) \sinh(\omega\sqrt{1-\rho^2})t + \cosh(\omega\sqrt{1-\rho^2})t], \quad (16)$$

where the variables are defined in equation (15) above.

The predicted values of the parameters are:

$$\omega = 0.0613 \text{ rad/sec}$$

$$\rho = 2.489.$$

Table 2 shows the predicted values for the N-butyl alcohol with a time constant of 82 seconds.

The determination of the tilt requires the conversion of four pairs of frequencies recorded on the data logger, using the system geometry, in a digital computer program. Ideally, this computation would be done with a microcomputer at the test site. However, the data logger was constructed so that long term data may be stored in memory and then the data logger disconnected from the system and brought to the laboratory for interrogation. Field tilt data was not analyzed since the system was turned over to the Geological Survey after the dynamic test runs. Sample runs were made previously in the laboratory.

Appendix E gives a listing of a computer code (TILT) run on a PDP 1143 computer to compute the tilt for a single or multiple leg system. The details of the computer code are explained in the comment cards within the code. Note that the frequency (counts) for the different transducers are compared with bounds based on the reference target counts to automatically detect malfunctions in the transducers. A copy of the data as obtained from the data logger and used directly by the computer program for tilt calculations is also given in Appendix D for reference.

CONCLUSIONS AND RECOMMENDATIONS

The two fluid tiltmeter system has been successfully installed in the test site at San Juan Bautista, California. The dynamic response can be accurately determined theoretically using linear theory as demonstrated by field experiments on both methyl ethyl ketone and N-butyl alcohol legs of the system.

The thermally compensated pier performs satisfactorily in a laboratory test and can be assembled and installed with minimal effort at a remote test site. Computer codes needed to evaluate field combinations based on thermal error conditions and dynamic response are available. A computer program to determine tilt from the recorded frequencies obtained from the measurement system and data logger is operational.

It is recommended that a third reservoir, transducer driver package be constructed and appropriate modifications made to the data logger so that both legs of the system can be operated simultaneously. Long-term tilt data must be taken to supplement the response data already taken to qualify the instrument.

REFERENCES

1. Eaton, J. P., "A Portable Water-Tube Tiltmeter", Bull. Seismol. Soc. Amer., 49, 301-316, 1959.
2. Bevan, J., Bilham, R., "Thermally Induced Errors in Fluid Tube Tiltmeters", Journal of Geophysical Research, Vol. 82, No. 9, 5699-5704, 1977.
3. Huggett, G. R., Slater, L. E., and Pavlis, G., "Precision Leveling with a Two-Fluid Tiltmeter", Geophysical Research Letters, Vol. 3, No. 12, 754-756, 1976.
4. Huggett, G. R., "Two-Fluid Tiltmeter", Final Report USGS Contract No. 14-08-0001-16818, Terra Technology Corporation, Redmond, Washington 98052, July 2, 1979.
5. International Critical Tables of Numerical Data, Physics, Chemistry, and Technology, McGraw-Hill, New York, 1928.
6. Merchant, H. C., Slater, L. E., "Vertical Displacement Measurements in Central California with a Long-Baseline Two-Fluid Tiltmeter", Semi-Annual Report USGS No. 14-08-0001-18224, December, 1980.

TABLE 1
RESPONSE TO AN INITIAL DISPLACEMENT

Methyl Ethyl Ketone

<u>Time(sec)</u>	<u>Fluid Height (cm)</u>		<u>Ratio H/Ho</u>
	<u>Measured</u>	<u>Predicted</u>	
0	13.36	-----	-----
15	13.11	12.96	0.664
28	12.85	12.72	0.465
36.5	-----	-----	0.369
38	12.60	12.60	0.354
53	12.34	12.46	0.235
71	12.09	12.36	0.143

TABLE 2
RESPONSE TO AN INITIAL DISPLACEMENT

N-Butyl Alcohol

<u>Time(sec)</u>	<u>Fluid Height (cm)</u>		<u>Ratio H/Ho</u>
	<u>Measured</u>	<u>Predicted</u>	
0	13.77	-----	-----
10	13.51	13.54	0.92
17	13.26	13.31	0.84
26	13.00	13.06	0.75
33	12.75	12.85	0.68
47	12.50	12.55	0.57
75	12.24	12.07	0.40
82	-----	-----	0.364

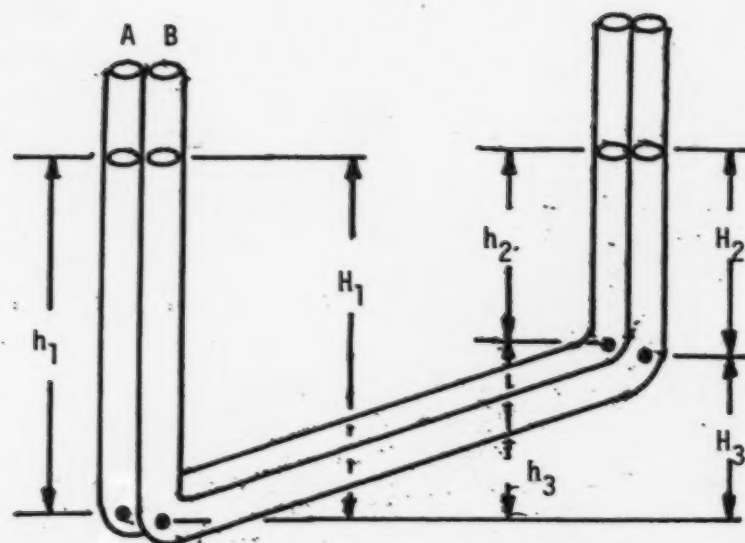


Figure 1

Thermal Compensation Schematic

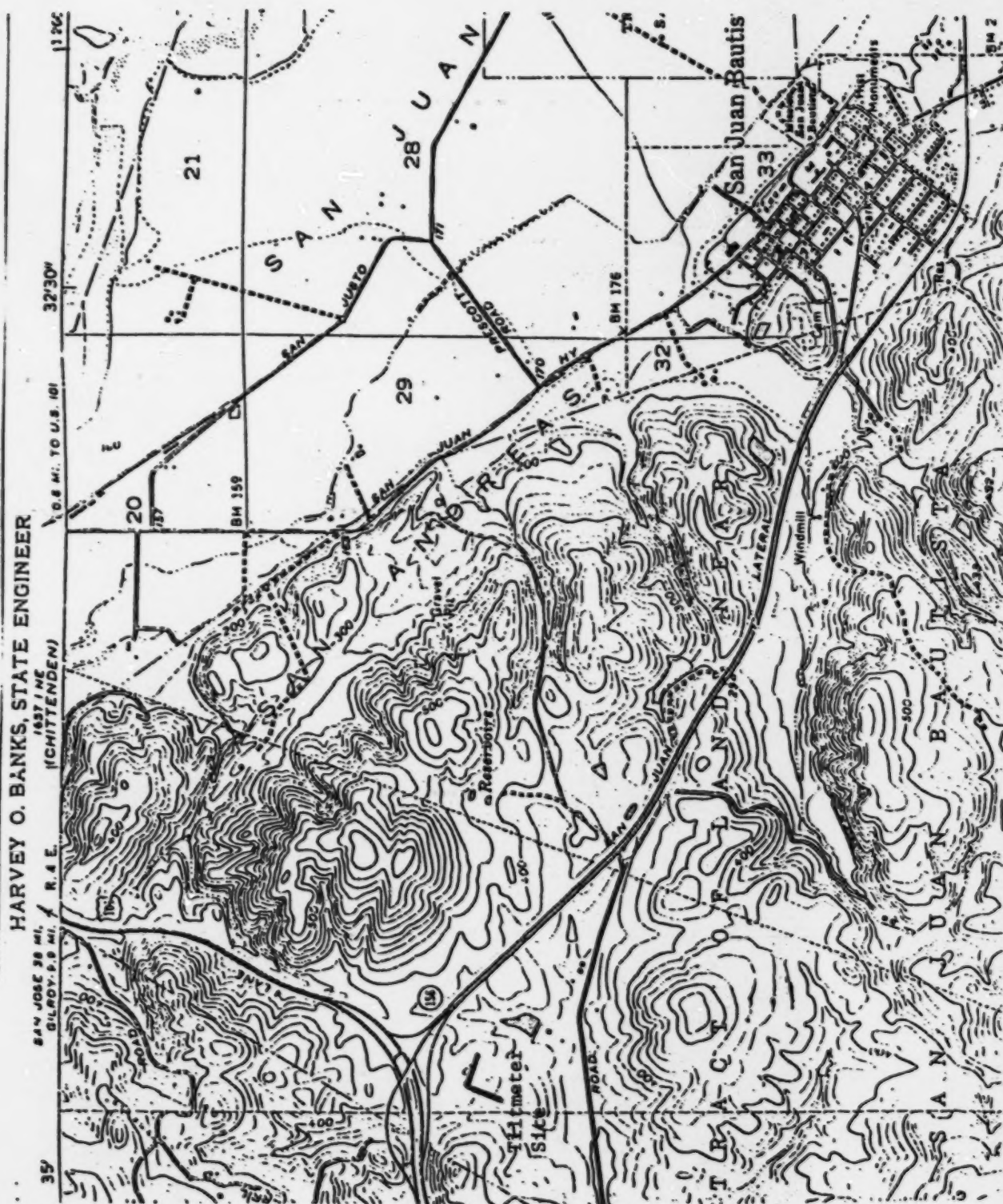


Figure 2
Tiltmeter Site

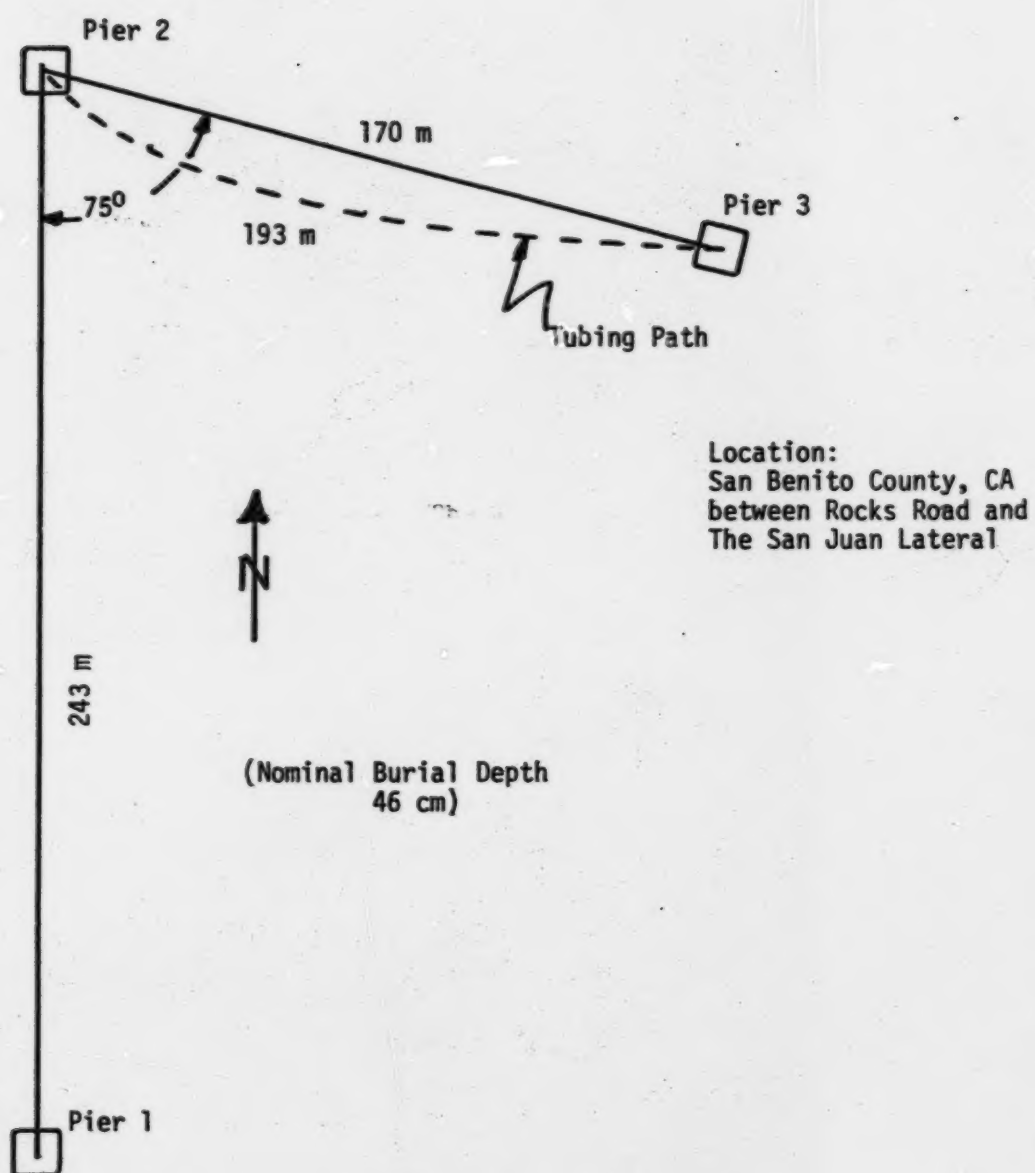


Figure 3
Tiltmeter Geometry



Figure 4
View Toward Station One



Figure 5
View Toward Station Two

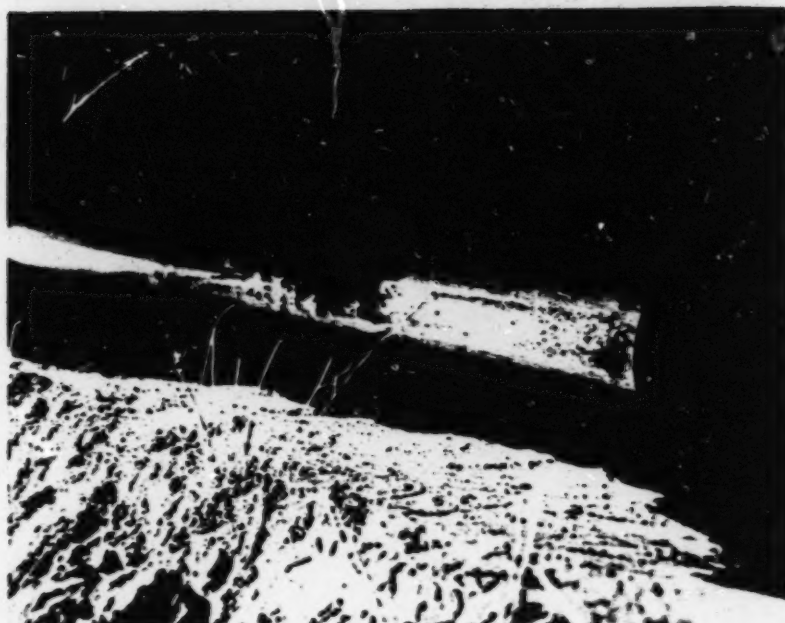


Figure 6
Joint Protection

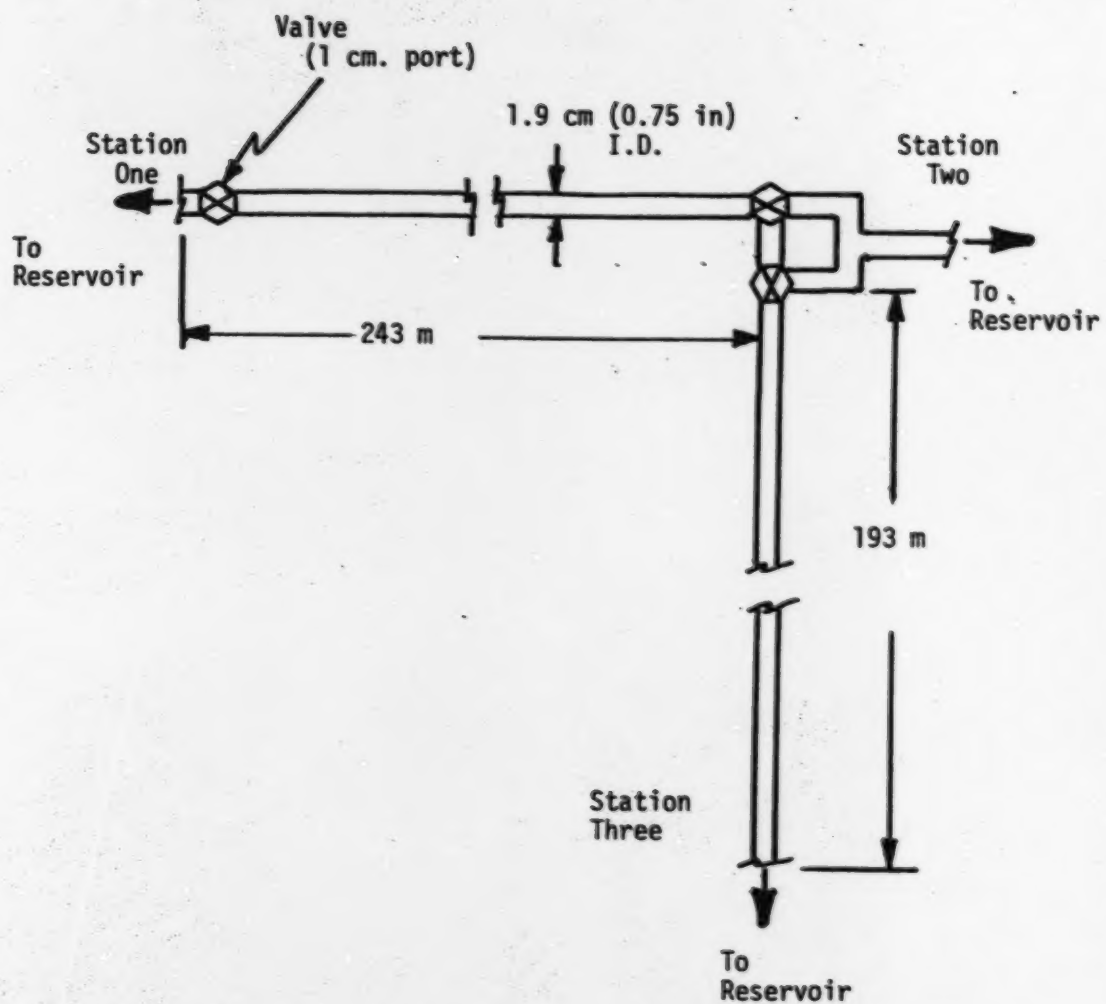


Figure 7

M.E.K.
Layout

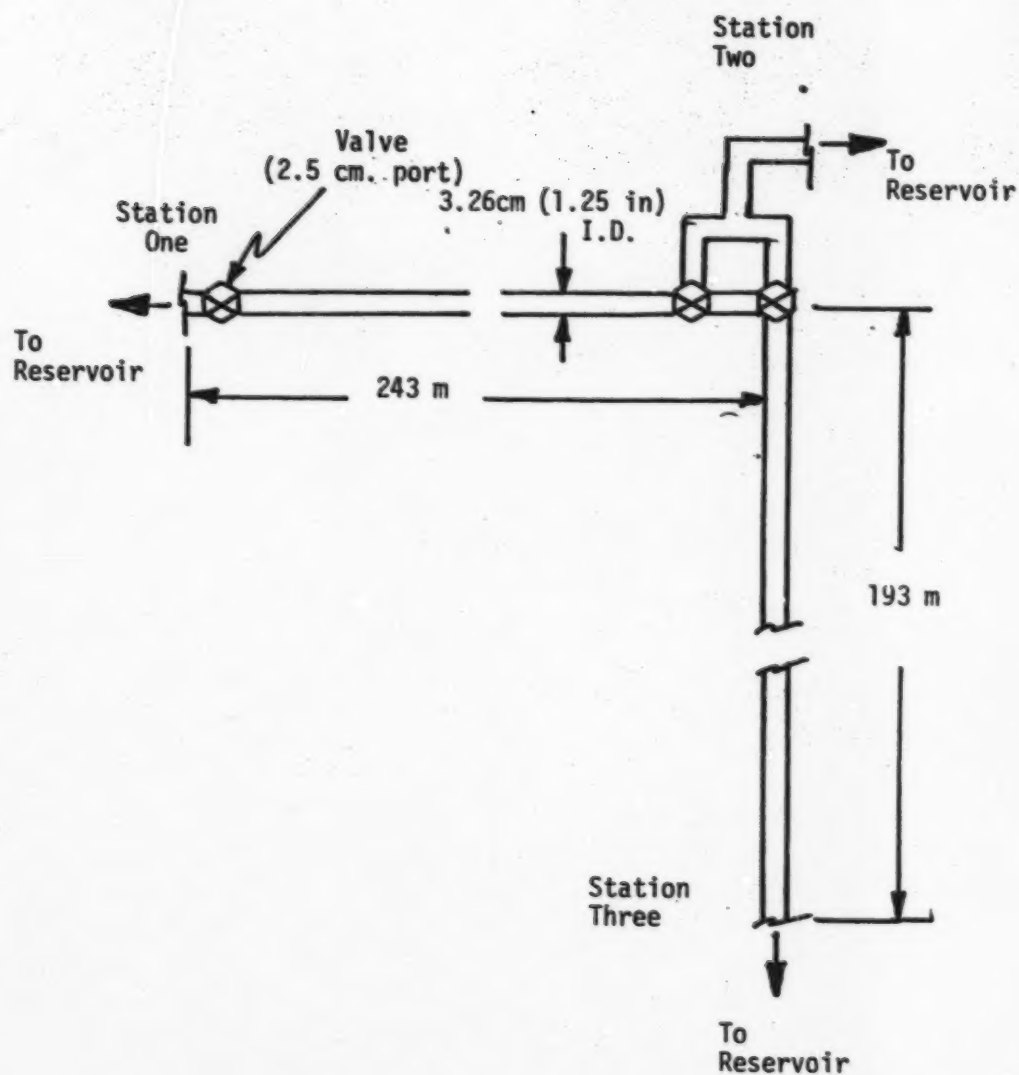


Figure 8

Alcohol
Layout

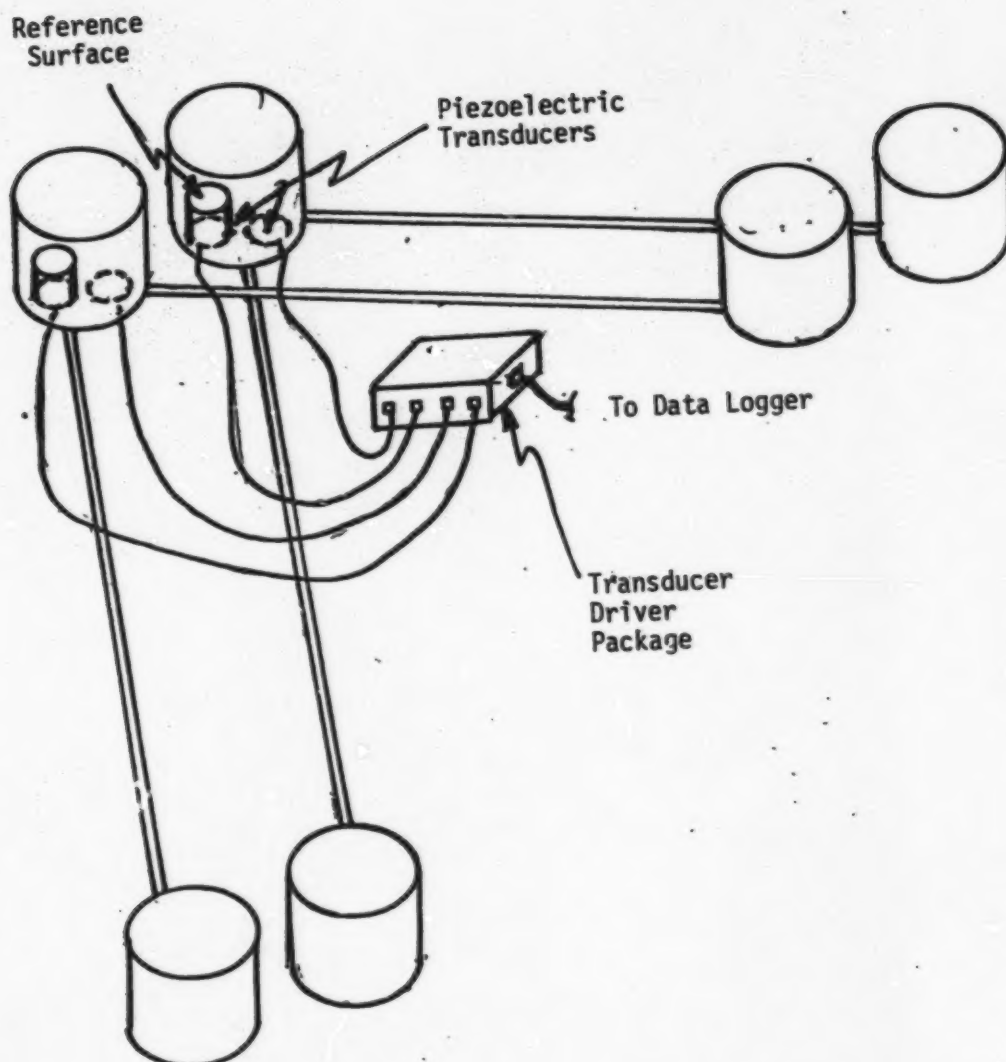


Figure 9
Transducer Locations

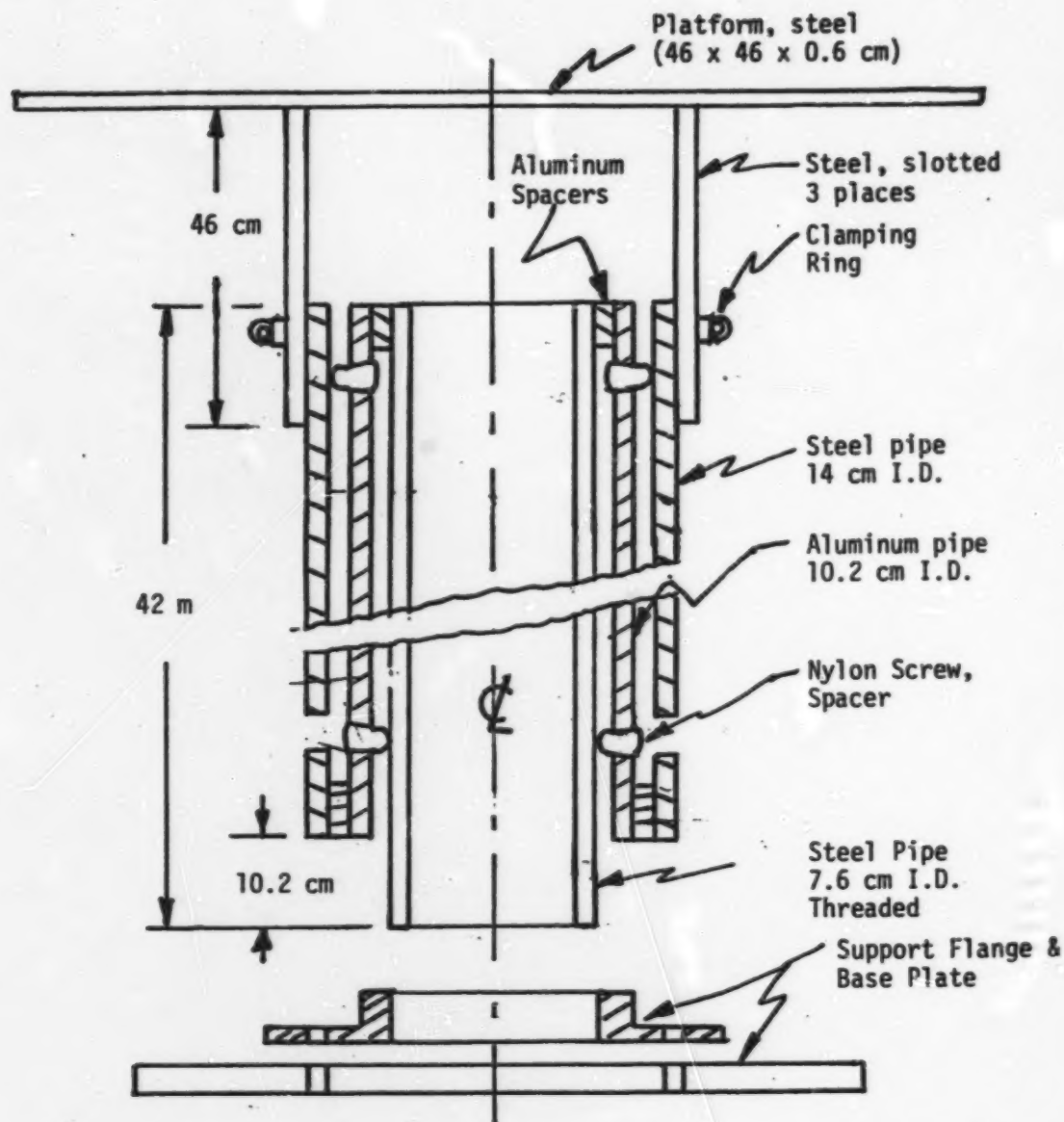


Figure 10
Compensated Pier

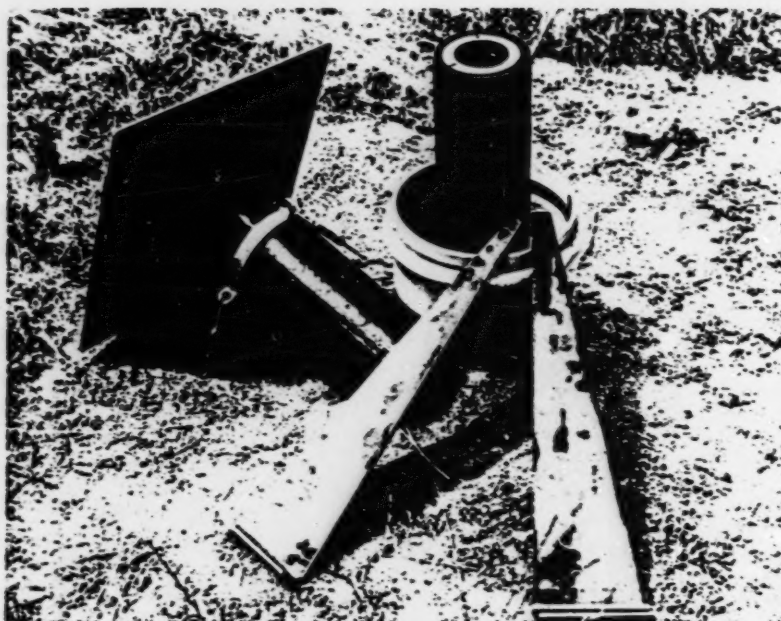


Figure 11
Pier Components

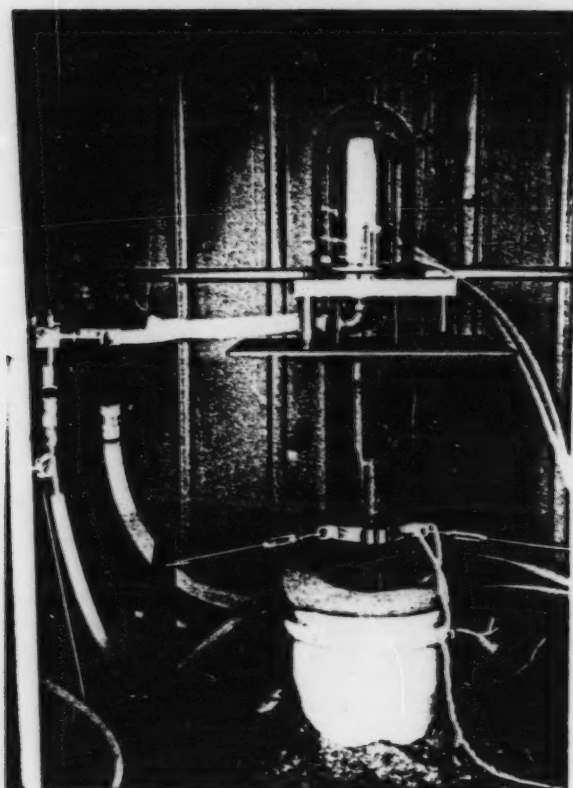


Figure 12

Station One, Complete

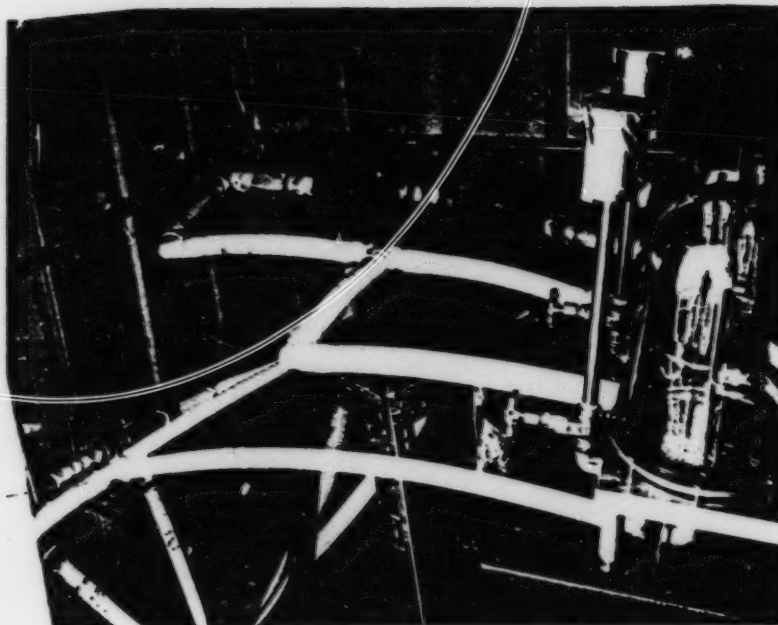


Figure 13
Station Two, Complete

APPENDICES

Appendix A

Fluid Properties Selection

1. Program FLUIDPH
2. Sample Output
3. Properties of Fluids Selected

1. FLUIDPH

UNIVERSITY OF MINNESOTA FORTRAN COMPILER (VERSION 5.4 - 02/22/79) ON 01/17/80 AT 19.35

MNE,T.

```

C *****
C *****
C      THIS PROGRAM IS TO AID IN THE SELECTION OF THE FLUIDS
C      FOR THE TWO-FLUID TILTMETER
C      T=TEMPERATURE IN C.
C      DO(L)=DENSITY OF THE FLUID AT 0 C.
C      D(L)=DENSITY OF THE FLUID AT TEMPERATURE T.
C      A(L),B(L),C(L) ARE THE COEFFICIENTS IN THE EQUATION
C      D(L)=DO(L)+A*T+B*T**2+C*T**3+.....
C      MP,MELTING POINT OF THE FLUID
C      BP,BOILING POINT OF THE FLUID
C *****
C *****
C      MAIN PROGRAM
C *****
1. 0000008      PROGRAM FLUID(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C *****
C      DIMENSION
C *****
2. 0021318      DIMENSION NAME(80,2),D(80),A(80),B(80),C(80),ALPHA(80),
      1BETA(80),GAMMA(80),RATIOA(80,80),RATIOB(80,80),RATIOC(80,80),
      2ECOE(80,80),MP(80),BP(80),RATIOD(80,80),RATIOE(80,80)
C *****
3. 0021318      E=0.5
4. 1167118      L=47
5. 1167138      DO 10 J=1,L
6. 1167228      READ(5,1000)NAME(J,1),NAME(J,2),D(J),A(J),B(J),C(J),MP(J),BP(J)
7. 1170018      10 CONTINUE
C *****
8. 1170058      WRITE(6,2000)
9. 1170138      DO 15 J=1,L
10. 1170228      ALPHA(J)=A(J)/D(J)
11. 1170278      BETA(J)=B(J)/D(J)
12. 1170348      GAMMA(J)=C(J)/D(J)
13. 1170418      15 CONTINUE
14. 1170448      J=1
15. 1170458      20 DO 850 K=1,L
16. 1170568      RATIOA(J,K)=ALPHA(J)/ALPHA(K)
17. 1170738      IF(BETA(K))40,30,40
18. 1171018      30 RATIOB(J,K)=0.0

```

```

18. 1171018 30 RATIOB(J,K)=0.0
19. 1171128 GO TO 50
20. 1171148 40 RATIOB(J,K)=BETA(J)/BETA(K)
21. 1171348 50 IF(GAMMA(K)).70,60,70
22. 1171448 60 RATIOC(J,K)=0.0
23. 1171548 GO TO 80
24. 1171568 70 RATIOC(J,K)=GAMMA(J)/GAMMA(K)
25. 1171768 80 IF(RATIOA(J,K)-1.0)90,850,100
26. 1172128 90 IF(RATIOA(J,K)-0.95)105,850,850
27. 1172268 100 IF(RATIOA(J,K)-1.05)850,850,101
28. 1172428 101 IF(ABS(RATIOA(J,K)-RATIOB(J,K))-E)110,110,850
29. 1172608 105 RATIOD(J,K)=1/RATIOA(J,K)
30. 1172728 IF(RATIOB(J,K))107,106,107
31. 1173028 106 RATIOB(J,K)=0.0000001
32. 1173138 107 RATIOE(J,K)=1/RATIOB(J,K)
33. 1173258 IF(ABS(RATIOD(J,K)-RATIOE(J,K))-E)110,110,850
34. 1173408 110 ECOEF(J,K)=(BETA(J)*ALPHA(K)-ALPHA(J)*BETA(K))/(ALPHA(J)-ALPHA(K))
35. 1173638 WRITE(6,3000)NAME(J,1),NAME(J,2),MP(J),BP(J),NAME(K,1),NAME(K,2),
      1MP(K),BP(K),RATIOA(J,K),RATIOB(J,K),RATIOC(J,K),ECOEF(J,K)
36. 1175028 850 CONTINUE
37. 1175068 J=J+1
38. 1175078 IF(J=L)20,20,900
39. 1175078 900 CONTINUE
C * * * * *
C
C          F O R M A T   S E C T I O N
C * * * * *
40. 1175128 1000 FORMAT(2A10,4F12.8,2A5)
41. 1175128 2000 FORMAT(1H1,40X,↑FLUIDS SELECTION FOR THE TWO-FLUID TILTMETER↑,
      120X,↑A-R. MANNA↑,///,4X,↑NAME OF FLUID↑,10X,↑MP 3P↑,7X,
      2↑NAME OF FLUID↑,8X,↑MP BP↑,6X,↑RATIO A↑,8X,↑RATIO B↑,8X,
      3↑RATIO C↑,3X,↑ERROR COEFFICIENT↑,/)
42. 1175128 3000 FORMAT(2X,2(A10),2X,A5,2X,A5,2X,2(A11),2X,A5,2X,A5,2X,4(E12.8,3X),
      1//)
C * * * * *
43. 1175128 STOP
44. 1175138 END

```

2. Sample Output.

 FLUIDS SELECTION FOR THE TAD-FLUID-TILMETER

NAME OF FLUID	MP	BP	NAME OF FLUID	MP	BP
ALPH-EPICHLOROHYDRIN	-25.6	117.0	BROMOBENZENE--C ₆ H ₅ BR	-30.6	156.2
ALPH-EPICHLOROHYDRIN	-25.6	117.0	CHLOROBENZENE-C ₆ H ₅ Cl	-45.2	132.1
ALPH-EPICHLOROHYDRIN	-25.6	117.0	IODOBENZENE--C ₆ H ₅ I--	-31.4	189.6
ALPH-EPICHLOROHYDRIN	-25.6	117.0	BENZONITRILE---C ₇ H ₅ N	-13.1	191.7
ALPH-EPICHLOROHYDRIN	-25.6	117.0	METHYLANILINE--C ₇ H ₉ N	-57.0	195.7
ALPH-EPICHLOROHYDRIN	-25.6	117.0	QUINOLINE-----C ₉ H ₇ N	-19.5	237.7
ALPH-EPICHLOROHYDRIN	-25.6	117.0	ETHYL-----BENZOATE	-34.6	213.2
ALPH-EPICHLOROHYDRIN	-25.6	117.0	CYME NE-----C ₁₀ H ₁₄	-25.0	175.0
ALPH-EPICHLOROHYDRIN	-25.6	117.0	DIETHYLANILINE-----	-34.4	216.3
METHYL-ETHYL-KETONE	-86.4	079.6	NBUTYL-ALCOHOL-C ₄ H ₁₀ O	-89.8	117.7
METHYL-ETHYL-KETONE	-86.4	079.6	ACETYLACETONE-C ₅ H ₈ O ₂	-23.2	137.0
METHYL-ETHYL-KETONE	-86.4	079.6	DIETHYLKETONE-C ₅ H ₁₀ O	-42.0	131.7
METHYL-ETHYL-KETONE	-86.4	079.6	METHYL--N--BUTYRATE-	-95.0	109±3
METHYL-ETHYL-KETONE	-86.4	079.6	DIETHYL---OXALATE---	-40.6	195.1
METHYL-ETHYL-KETONE	-86.4	079.6	ETHYL--N--BUTYRATE--	-93.3	121.3
METHYL-ETHYL-KETONE	-86.4	079.6	BENZYL-ALCOHOL-C ₇ H ₈ O	-15.3	205.8

 FLUIDS SELECTION FOR THE TAD-FLUID TILMETER

BP	RATIO A	RATIO B	RATIO C	ERROR COEFFICIENT
156.2	1.14584633	1.31804470	0	-.00000019
132.1	1.07069363	.93742831	0	.00000042
188.6	1.27152207	.92053366	0	.00000029
133.7	1.18229838	1.51808720	0	-.00000025
195.7	1.26415705	.86815657	0	.00000036
237.7	1.48864307	1.77266421	0	-.00000007
213.2	1.19200853	.92218366	0	.00000032
175.0	1.12639079	.64817673	0	.00000121
216.3	1.22621063	.75989591	0	.00000056
117.7	1.45923717	1.43469643	0	.00000002
137.0	1.22829084	1.38903829	0	-.00000026
131.7	1.09802064	.70388443	0	.00000318
109.3	1.06413960	.72209327	0	.00000412
195.1	1.19120476	1.46167074	0	-.00000054
121.3	1.08035780	1.08987172	0	-.00000006
205.8	1.70951208	1.28514494	0	.00000026

3. Fluid Properties

N-BUTYL ALCOHOL

Density = $0.823 \text{ gm/cm}^3 (0^\circ\text{C})$

$\alpha = -8.49 \times 10^{-4} / ^\circ\text{C}$

$\beta = -3.88 \times 10^{-7} / ^\circ\text{C}^2$

Temp $^\circ\text{C}$	Viscosity (poise)
0	0.07911
10	0.05735
20	0.03658
30	0.030658
40	0.022392

METHYL ETHYL KETONE

Density = $0.82251 \text{ gm/cm}^3 (0^\circ\text{C})$

$\alpha = -1.24 \times 10^{-3} / ^\circ\text{C}$

$\beta = -5.59 \times 10^{-7} / ^\circ\text{C}^2$

Temp $^\circ\text{C}$	Viscosity (poise)
0	0.05361
10	0.04522
20	0.04170
30	0.03861
40	0.03342

Appendix B

Safety Considerations

- 1. Hygienic Guides for Fluids Selected**
- 2. Respirator Specifications**

1 - Hygenic Guides



AMERICAN

Industrial
Hygiene

ASSOCIATION

Hygienic Guide Series

HYGIENIC GUIDE SERIES

METHYL ETHYL KETONE (Butanone)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 250 parts of vapor per million parts of air, by volume (ppm).¹

- (1) *Basis for Recommendation:* Human experience plus animal studies.

B. SEVERITY OF HAZARDS:

- (1) *Health:* Low, for both acute and chronic exposures. Capable of causing narcotic symptoms in man and animals, but irritant properties of vapor limit the possibility of voluntary exposure to high concentrations. No confirmed reports of serious chronic effects below irritating levels. It may cause drying and irritation of the skin.

- (2) *Fire:* High. Flash point is -5.6°C (22°F) (open cup). Explosive limits are 1.8-11.5% by volume.²

C. SHORT EXPOSURE TOLERANCE: Limited by irritant properties of vapor; 30,000 ppm is intolerable to man because of irritation of eyes and nasal passages; 3000 ppm is intolerable for more than just a short period of time.^{4,5}

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown, but probably 10,000 ppm or above.

II. Significant Properties

It is a colorless liquid with a characteristic ketonic odor. Although the product now available usually has a high degree of purity, the following properties will be somewhat modified for the commercial grade:

Chemical formula: $\text{CH}_3\text{COCH}_2\text{CH}_3$
 Molecular weight: 72.10
 Specific gravity: 0.805 ($20^{\circ}/4^{\circ}\text{C}$)
 Boiling point: 79.6°C

Relative vapor density: 2.49 (air = 1)
 Vapor pressure: 90.7 mm Hg, at 25°C
 At 25°C and 760 mm Hg,
 1 mg/liter of vapor: 340 ppm
 1 ppm of vapor: 0.00294 mg/liter
 Solubility: Moderately, in water; forms azeotropic mixture with water (boiling point 73.5°C), at 89% by weight methyl ethyl ketone

III. Industrial Hygiene Practice

A. RECOGNITION: It has been widely used as a solvent for resins and lacquers, in paint removers, and in miscellaneous organic syntheses. It can be recognized by its characteristic odor (somewhat similar to acetone, but slightly more irritating).

B. EVALUATION OF EXPOSURES: Can be determined by methods similar to those used for other ketones. It can also be determined by mass spectrometry and by suitably calibrated explosimeter type instruments.^{3,5}

C. RECOMMENDED CONTROL PROCEDURES: Any operations involving spraying should be conducted in a properly designed spray booth. It should be used only in the presence of spark proof equipment and with due care, to avoid exposure to any other sources of ignition. Occasional short exposures to small quantities can usually be controlled by good general ventilation. If irritating levels are encountered, this can be controlled by the use of personal respiratory protective equipment.

IV. Specific Procedures

A. FIRST AID: Remove any contaminated clothing promptly and flush skin with copious amounts of water.

Reviewed—Second Printing
April, 1964

ous amounts of water. In case of eye burns, flush with water for 10 minutes.

B. PROPHYLACTIC PROCEDURES: Attempt to maintain workroom atmospheres below 250 ppm.

C. SPECIAL MEDICAL PROCEDURES: None generally necessary. If trapped in an area of high concentrations, causing narcotic symptoms, remove individual to fresh air and treat symptomatically.

V. Literature References

1. AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS: *AMA Arch. Ind. Health*, 14:186, 1956.
2. ELKINS, H. B.: *The Chemistry of Industrial Toxicology*, p. 323. John B. Wiley and Sons, Inc., New York, 1950.
3. FAIRHALL, L. T.: *Industrial Toxicology*, p. 235. The Williams and Wilkins Co., Baltimore, 1949.
4. LA BALLA, M. S., and BEINSON, H.: *AMA Arch. Ind. Health*, 12:623, 1953.
5. MARSDEN, C.: *Solvents and Allied Substances Manual*. Elsevier Press, Houston, Tex., 1954.
6. PATTY, F. A., SCHERER, H. H., and YANT, W. P.: *Public Health Reports*, 50:1217-1228, 1935.

Because of space limitations, it is impossible to list all methods of exposure evaluation. The selections have been made on the basis of current usage, reliability, and applicability to the usual industrial type of exposure. Any specific evaluation and/or control problem will involve professional judgment. This can best be done by professional industrial hygiene personnel.

Respiratory protective devices are commercially available. Their use, however, should be confined to emergency or intermittent exposures and not relied upon as primary means of hazard control.

A relative scale is used for rating the severity of hazards: nil, low, moderate, high, and extra hazardous.

HYGIENIC GUIDES COMMITTEE

WILLIAM E. MCCORMICK, Chairman
FRANCIS F. HEYROTH, M.D.
HERVEY B. ELKINS, Ph.D.
DAVID W. FASSETT, M.D.
CLYDE M. BERRY, Ph.D.

WILLIAM B. HARRIS
MELVIN W. FIRST, Sc.D.
H. E. STOKINGER, Ph.D.
PAUL D. HALLEY
EDWARD V. HENSON, M.D.

Hygienic Guide sheets may be obtained from the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, 14125 Prevoist, Detroit 27, Michigan at 25 cents each. All orders for less than \$2.00 must be prepaid. Discount of 20% on orders of five or more Guides; 40% discount on orders of 100 or more Guides. Special loose-leaf binders for the Guides may also be ordered from the Association office for \$1.25 each.



AMERICAN

Industrial Hygiene

ASSOCIATION

Hygienic Guide Series

HYGIENIC GUIDE SERIES

BUTYL ALCOHOL (N-BUTANOL)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 100 parts of vapor per million parts of air (ppm).¹

(1) *Basis for Recommendation:* Development of eye irritation upon prolonged exposure to levels over 100 ppm.^{2,4}

B. SEVERITY OF HAZARDS:

(1) *Health:* Low. Volatility is low and odor response good.

(2) *Fire:* Moderate. The limits of inflammability are 1.5% and 11.3% by volume.² Because of the low volatility, however, explosive atmospheres are unlikely, except at elevated temperatures. Flash point is 84°F (closed cup).

C. SHORT EXPOSURE TOLERANCE: Occasional eye irritation at 200 ppm with several hours exposure.²

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown.

II. Significant Properties

Butanol is a flammable, colorless liquid, slightly soluble in water, miscible with most organic solvents. It has a pungent odor resembling fusel oil.

Chemical formula: $C_4H_9CH_2CH_2OH$

Molecular weight: 74

Specific gravity: 0.810 (20°/4°C)

Boiling point: 117.7°C

Relative density: 2.56 (air = 1)

Vapor pressure: 6 mm of Hg at 25°C

Solubility: In most organic solvents and in water to the extent of 8.9% at 25°C

1 ppm of vapor
(25°C and 760
mm Hg):

0.00303 mg/l

1 mg/l

(25°C and 760

mm Hg): 330 ppm

Odor threshold: Ca. 25 ppm

III. Industrial Hygiene Practice

A. RECOGNITION:

(1) May be recognized by its odor. It is a lacquer solvent, as well as an ingredient of some rubber and plastic cements. It is also used in the plastic fabrication and chemical manufacturing industries.

(2) By its irritant action on the conjunctiva and mucous membranes, and by its minor skin irritant effects.

B. EVALUATION OF EXPOSURES: Because it is frequently used in association with other alcohols, a specific analytical method is difficult to achieve. In the absence of other alcohols an iodometric estimation of the amount of chromate necessary to oxidize it to butyric acid has been used by Tabershaw.⁴ A DAVIS M-6 VAPO-TESTER, properly calibrated, has also been used. The vapors may also be determined by either a gas interferometer or a mass spectrometer.

C. RECOMMENDED CONTROL PROCEDURES: Enclosure of the processes using butanol should be practiced. Adequate ventilation of the surfaces of the benches at which the cementing operations are conducted is recommended.

IV. Specific Procedures

A. FIRST AID: Usual procedures, such as removal from exposure, washing of affected skin areas, and irrigation of the eyes with water should be practiced.

B. PROPHYLACTIC PROCEDURES: Maintain

Reviewed—Second Printing
April, 1964

workroom atmospheres below 100 ppm by means of process enclosure and/or ventilation. This can best be done by personnel specifically trained in industrial hygiene procedures.

C. SPECIAL MEDICAL PROCEDURES (including preplacement): None.

V. Literature References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. of Ind. Health.*, 11:321, 1953.
2. Cowan, H. F., and Jones, G. W.: U. S. Bureau of Mines, Bulletin 503, 1952.
3. Symons, J. H., Caduch, H. C., Brockmeyer, H. F., and Cusack, M.: *AIHA Quarterly* 19:53, 1969.
4. Tashershaw, I. R., Fark, J. P., and Skinner, J. B.: *J. Ind. Hyg. and Tox.*, 26:328, 1944.

HYGIENIC GUIDES COMMITTEE

WILLIAM E. MCCORMICK, *Chairman*
FRANCIS F. HEYROTH, M.D.
HERVEY B. ELKINS, Ph.D.
DAVID W. FASSETT, M.D.

WILLIAM B. HARRIS
MELVIN W. FIRST, Sc.D.
H. E. STOKINGER, Ph.D.
H. E. SEIFERT

CLYDE M. BERRY, Ph.D.

Hygienic Guide sheets may be obtained from the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, 14125 Prevoist, Detroit 27, Michigan at 25 cents each. All orders for less than \$2.00 must be prepaid.

2 - Respirator Specifications

Appendix C

Dynamic Response

1. Program DYNAM
2. Sample Output

1. Program DYNAM

MNF,T.

```

1. 000000B      PROGRAM DYNAM(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
2. 002131B      DIMENSION VISC(50,50),R11(50,50),R12(50,50),R22(50,50),
      1DENS(50,50),NAME(50,2),ALPH(50),BETA(50),GAMA(50),DENSR(50),
      2NDP(10),AP(10)
3. 002131B      PI=3.14159
4. 033155B      N=10
5. 033157B      D=16.51
6. 033160B      G=980.0
7. 033161B      PL=25000.0
8. 033163B      NDP=2
9. 033164B      DO 10 N=1,NDP
10. 033173B      READ(5,50)DP(N)
11. 033207B      10 CONTINUE
12. 033213B      DO 20 J=1,M
13. 033222B      READ(5,100)NAME(J,1),NAME(J,2)
14. 033243B      20 CONTINUE
15. 033247B      READ(5,150)((VISC(J,K),K=1,5),J=1,M)
16. 033305B      DO 40 J=1,M
17. 033314B      DO 30 K=1,5
18. 033317B      VISC(J,K)=VISC(J,K)/100.0
19. 033317B      30 CONTINUE
20. 033342B      40 CONTINUE
21. 033347B      READ(5,155)(DENSR(J),ALPH(J),BETA(J),GAMA(J),J=1,M)
22. 033413B      TEMP=0.0
23. 033413B      T=0.0
24. 033413B      AR=(PI*NDP**2)/4.0
25. 033416B      DO 450 N=1,NDP
26. 033426B      AP(N)=(PI*DP(N)**2)/4.0
27. 033434B      W011=SQRT((2.0*G*AP(N))/(RL*AP))
28. 033452B      W012=SQRT((G*AP(N))/(RL*AP))
29. 033467B      W022=SQRT((3.0*G*AP(N))/(RL*AP))
30. 033506B      WRITE(4,500)DP(N),W011,W012,W022
31. 033525B      DO 400 J=1,M
32. 033534B      WRITE(6,550)NAME(J,1),NAME(J,2)
33. 033555B      DO 350 K=1,5
34. 033557B      IF(VISC(J,K))320,320,140
35. 033570B      140 DENS(J,K)=DENSR(J)+ALPH(J)*TEMP+BETA(J)*TEMP**2+GAMA(J)*TEMP**3

```

```

36. 033605H WRITE(A,580)TEMP,VISC(J,K),DENS(J,K)
37. 033622R R11(J,K)=(4.0*PI*VISC(J,K))/(W011*DENS(J,K)*AP(N))
38. 033634R R12(J,K)=(4.0*PI*VISC(J,K))/(W012*DENS(J,K)*AP(N))
39. 033644R R22(J,K)=(4.0*PI*VISC(J,K))/(W022*DENS(J,K)*AP(N))
40. 033655H WRITE(A,600)R11(J,K),R12(J,K),R22(J,K)
41. 033672R WRITE(A,650)
42. 033700R TF(R11(J,K)-1.0)296,160,200
43. 033703H 160 H0ATTN=(1.0+W011*T)*(EXP(-W011*T))
44. 033715H TF(T-800.0)190,190,195
45. 033720H 190 WRITE(A,700)HRATIO,T
46. 033731H T=T+300.0
47. 033732R GO TO 160
48. 033734H 195 TF(T-3600.0)196,196,290
49. 033740H 196 WRITE(A,700)HRATIO,T
50. 033751H T=T+600.0
51. 033752R GO TO 160
52. 033752H 200 CONTINUE
53. 033755H TF(R11(J,K)-1.0)296,270,250
54. 033760H 250 C=SQRT(R11(J,K)**2-1.0)
55. 033770H F=R11(J,K)*W011
56. 033772R H0ATTN=((R11(J,K)+C)/(2.0+C))*EXP((-F+W011*C)*T)
+((C-R11(J,K))/(2.0+C))*EXP((-F-W011*C)*T)

```

```

57. 034021R TF(T-900.0)260,260,265
58. 034025H 260 WRITE(A,700)HRATIO,T
59. 034036H T=T+300.0
60. 034037R GO TO 250
61. 034041H 265 TF(T-3600.0)266,266,290
62. 034045H 266 WRITE(A,700)HRATIO,T
63. 034056H T=T+600.0
64. 034057R GO TO 250
65. 034057H 270 CONTINUE
66. 034062H 290 TF(TEMP-40.0)295,360,360
67. 034066H 295 TEMP=TEMP+10.0
68. 034072H T=0.0
69. 034072R GO TO 350
70. 034074H 296 C=SQRT(1.0-R11(J,K)**2)
71. 034103H F=R11(J,K)*W011
72. 034105H S=ATAN(C/R11(J,K))
73. 034112H 297 H0ATTN=((EXP(-F*T))/C)*SIN((C*W011*T)+S)
74. 034134H TF(T-900.0)298,298,299
75. 034137H 298 WRITE(A,700)HRATIO,T
76. 034151H T=T+300.0
77. 034152R GO TO 297

```

```

78. 034154B 299 TF(T-3600.0)301,301,305
79. 034160B 301 WRTTF(6.700)HRATIO,T
80. 034171B T=T+600.0
81. 034172B GO TO 297
82. 034174B 305 TF(TEMP-40.0)306,360,360
83. 034177B 306 TEMP=TEMP+10.0
84. 034203B T=0.0
85. 034203B GO TO 350
86. 034205B 320 TVNT=(K-1)*10
87. 034210B WRTTF(6.540)NAME(J,1),NAME(J,2),TVNT
88. 034232B TEMP=TEMP+10.0
89. 034233B T=0.0
90. 034234B 350 CONTINUE
91. 034240B 360 TEMP=0.0
92. 034242B T=0.0
93. 034243B 400 CONTINUE
94. 034250B TF(N-NDP)440,900,900
95. 034250B 440 CONTINUE
96. 034254B TEMP=0.0
97. 034254B T=0.0
98. 034255B 450 CONTINUE
C * * * * * F O R M A T   S E C T I O N   * * * * *
99. 034262B 50 FORMAT(F10.5)
100. 034262B 100 FORMAT(2A10)
101. 034262B 150 FORMAT(5F10.5)
102. 034262B 155 FORMAT(4F12.8)
103. 034262B 500 FORMAT(1H1,20(//),30X,
1+THIS PROGRAM IS TO ESTIMATE THE SETTLING TIME FOR +,
2+THE OSCILLATING FLUIDS+,20X,1A-R MANNA+,///,40X,1PIPF DIAMETER
3 1DP =+,F10.5,///,20X,1FREQUENCY OF THE SINGLE LEG SYSTEM:W011=+,
4F10.5,///,20X,1FIRST FREQUENCY OF THE DOUBLE LEG SYSTEM:W012=+,
5F10.5,///,20X,1SECOND FREQUENCY OF THE DOUBLE LEG SYSTEM W022=+,
6F10.5,///)
104. 034262B 540 FORMAT(20X,1DATA FOR VISCOSITY OF +,2A10,1 AT A TEMP. OF +,
1J5,1 IS NOT AVAILABLE +,///) -
105. 034262B 550 FORMAT(1H1,40X,2A10,///)
106. 034262B 580 FORMAT(40X,1CALCULATION IS CARRIED OUT AT TEMP. =+,F10.3,2(5X,
1F10.5),///)
107. 034262B 600 FORMAT(20X,1DAMP. COEF. OF SINGLE LEG SYST. : R11=+,F10.5,///,20X,
1+FIRST DAMP. COEF. OF DOUBLE LEG SYST. : R12=+,F10.5,///,20X,
2+SECOND DAMP. COEF. OF DOUBLE LEG SYST. : R22=+,F10.5,///)
108. 034262B 650 FORMAT(20X,1HRATIO=(H/H0)+,10X,1SETTLING TIME+,///)
109. 034262B 700 FORMAT(30X,F10.8,15X,F10.2,///)
110. 034262B 900 STOP
111. 034264B END

```

2 - Sample Output

THIS PROGRAM IS TO ESTIMATE THE SETTLING TIME FOR THE OSCILLATING FLUIDS

PIPE DIAMETER :DP = 1.90500

FREQUENCY OF THE SINGLE LEG SYSTEM:W011 = .03436

FIRST FREQUENCY OF THE DOUBLE LEG SYSTEM:W012 = .02430

SECOND FREQUENCY OF THE DOUBLE LEG SYSTEM W022 = .04208

METHYL-ETHYL-KETONE

CALCULATION IS CARRIED OUT AT TEMP. = 0 .00536 .82251

DAMP. COEF. OF SINGLE LEG SYST. : B11= .83629

FIRST DAMP. COEF. OF DOUBLE LEG SYST. : B12= 1.18269

SECOND DAMP. COEF. OF DOUBLE LEG SYST. : B22= .68282

HRATIO=(H/HO.)

SETTLING TIME

1.00000000

0

-.00001667

300.00

-.00000004

600.00

-.00000000

900.00

-.00000000

1200.00

.00000000

1800.00

.00000000

2400.00

.00000000

3000.00

-.00000000

3600.00

THIS PROGRAM IS TO ESTIMATE THE SETTLING TIME FOR THE OSCILLATING FLUIDS

PIPE DIAMETER :DP = 3.17500

FREQUENCY OF THE SINGLE LEG SYSTEM:W011= .06530

FIRST FREQUENCY OF THE DOUBLE LEG SYSTEM:W012= .04617

SECOND FREQUENCY OF THE DOUBLE LEG SYSTEM W022= .07997

NBUTYL-ALCOHOLC4H100

CALCULATION IS CARRIED OUT AT IFMP. = 0 .07911 .82300

DAMP. COEF. OF SINGLE LEG SYST. : B11= 2.33652

FIRST DAMP. COEF. OF DOUBLE LEG SYST. : B12= 3.30434

SECOND DAMP. COEF. OF DOUBLE LEG SYST. : B22= 1.90776

HRATIO=(H/H0)

SETTLING TIME

1.00000000

0

.01288093

300.00

.00015753

600.00

.00000193

900.00

.00000002

1200.00

.00000000

1800.00

.00000000

2400.00

.00000000

3000.00

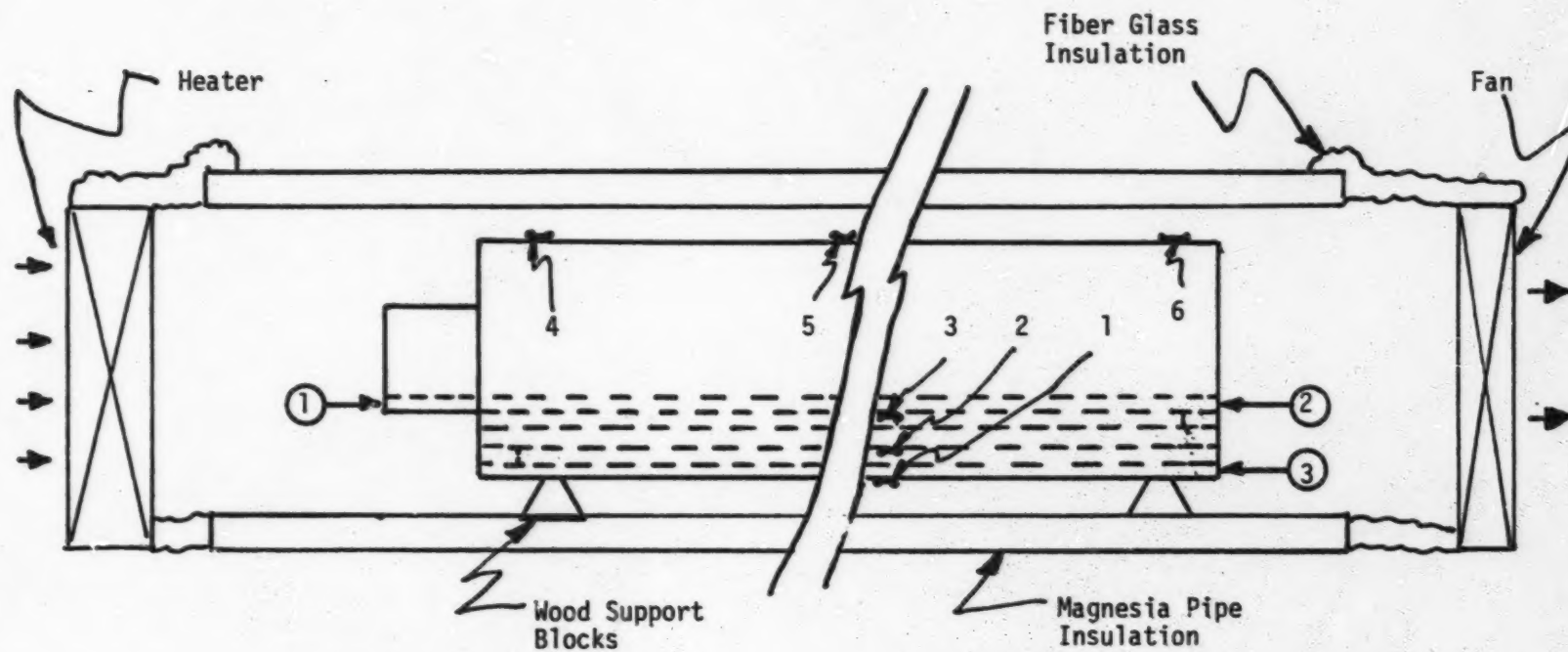
.00000000

3600.00

APPENDIX D

Thermally Compensated Pier Test

1. Schematic and Photograph of Test Set Up (D-1,D-2)
2. Cooling Data (D-3)
3. Heating Data (D-4)



1 - 6 Thermocouples
 ①-③ Dial Indicators

Figure D - 1
 Pier Thermal Expansion Test

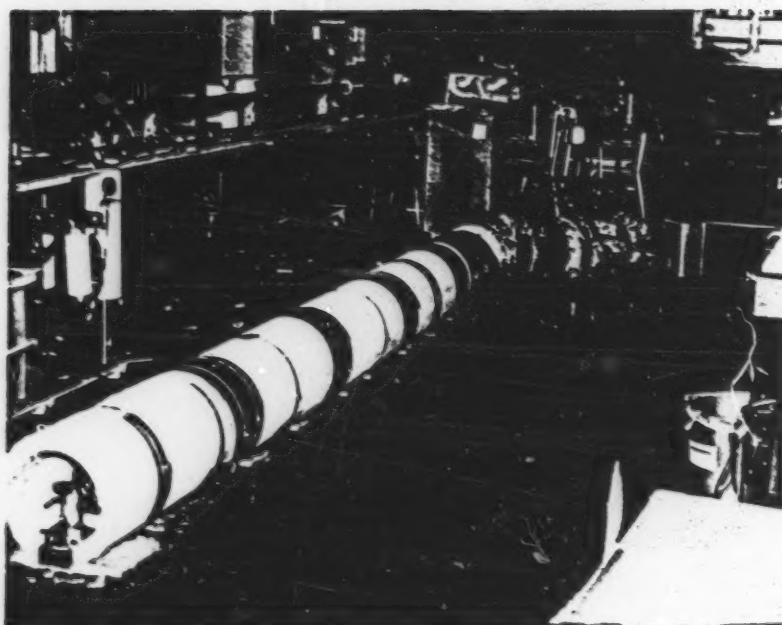


Figure D-2
Pier Thermal Test

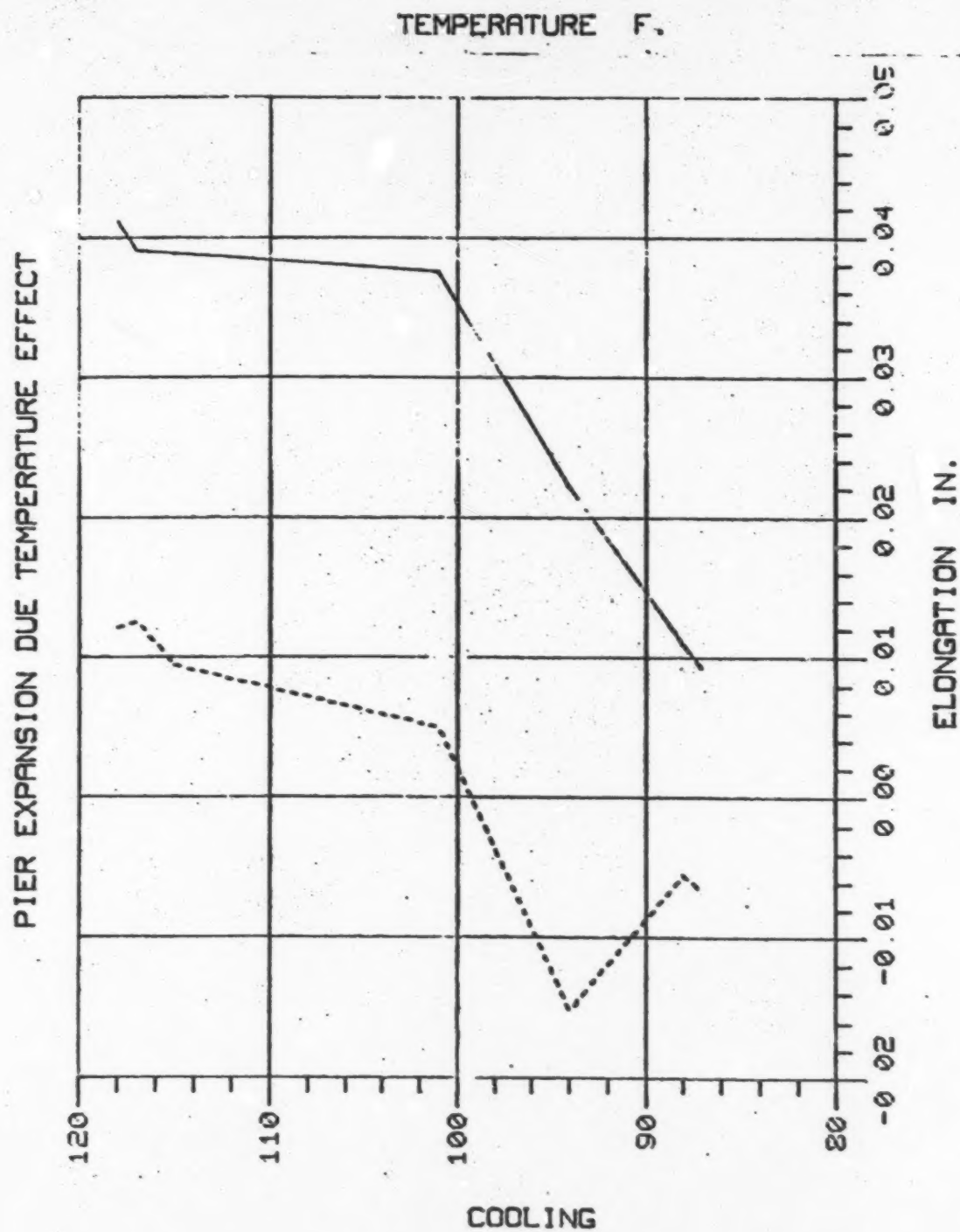
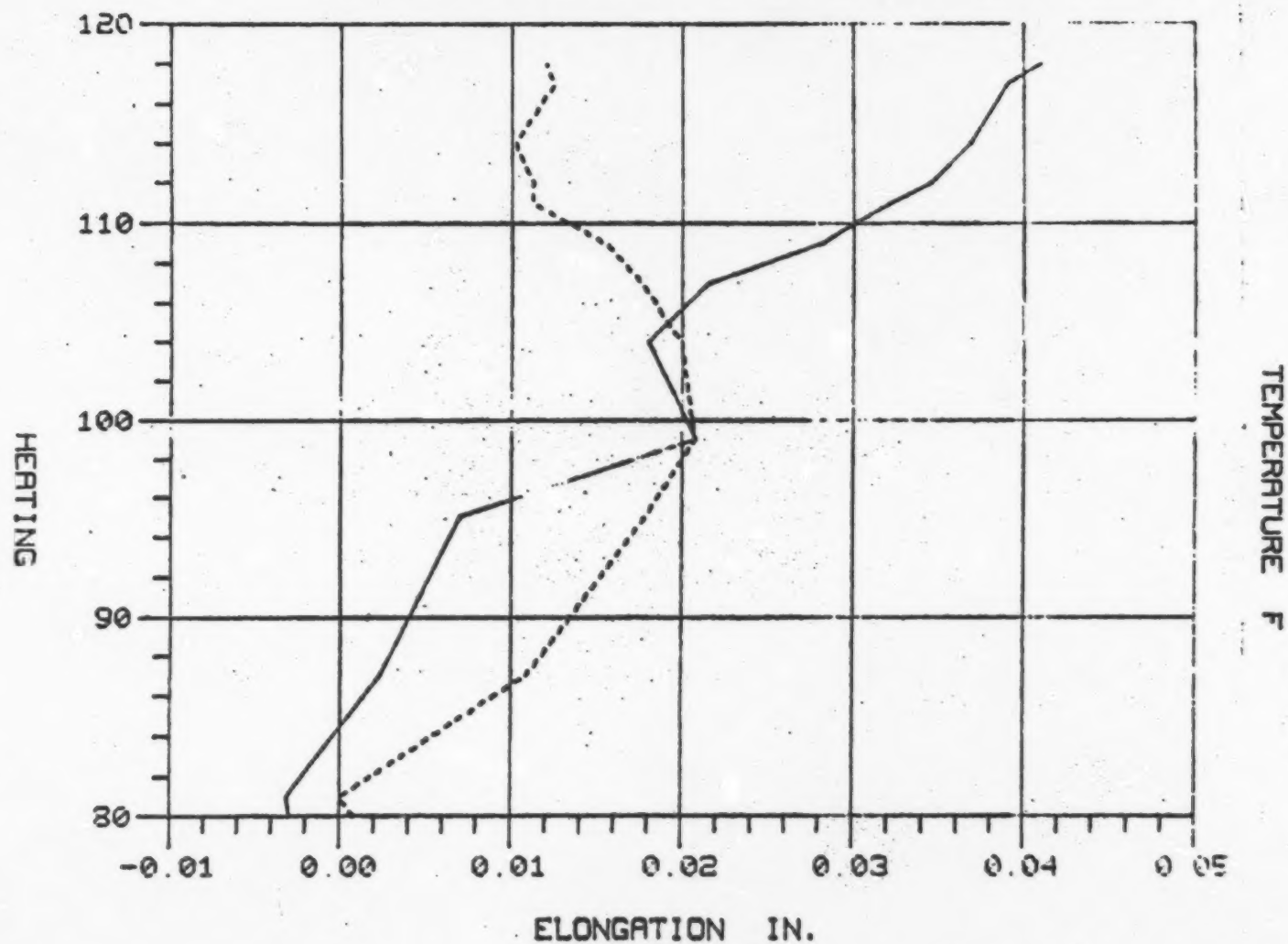


Figure D-3
Cooling Data

PIER EXPANSION DUE TO TEMPERATURE EFFECT



ELONGATION IN.

Figure D-4
Heating Data

Appendix E
Tilt Computations

1. Program TILT
2. Frequency data received from tiltmeter data logger.

1. Program Tilt

PROGRAM TILT

REAL ID, IH, IM, NRA3, NRM2, NSA2, NSM2, NSM1, NRM1, NRA4, NSA3, NSA4

```

C *****
C   NRA3=OSCILLATION COUNT BETWEEN REFERENCE AND ALCOHOL SURFACE
C   IN RESERVOIR NO. THREE
C   NRA4=OSCILLATION COUNT BETWEEN REFERENCE AND ALCOHOL SURFACE
C   IN RESERVOIR NO. FOUR
C   NRM1=OSCILLATION COUNT BETWEEN REFERENCE AND M.E.K. SURFACE
C   IN RESERVOIR NO. ONE
C   NRM2=OSCILLATION COUNT BETWEEN REFERENCE AND M. E.K. SURFACE
C   IN RESERVOIR NO. TWO
C   BH=LENGTH OF BASE LINE
C   N=NO. OF DATA LINES
C   ALPHA=THERMAL EXPANSION COEFFICIENT OF ALCOHOL
C   ALPHM=THERMAL EXPANSION COEFFICIENT OF M.E.K.
C   HR1=REFERENCE HEIGHT IN RESERVOIR NO. ONE
C   HR2=REFERENCE HEIGHT OF RESERVOIR NO. TWO
C   HR3=REFERENCE HEIGHT IN RESERVOIR NO. THREE
C   HR4=REFERENCE HEIGHT OF RESERVOIR NO. FOUR
C   LL=LOWER LIMIT OF FREQUENCY COUNT
C   UL=UPPER LIMIT OF FREQUENCY COUNT
C   HSA3=MEASURED ALCOHOL HEIGHT IN RESERVOIR NO. THREE
C   HSA4=MEASURED ALCOHOL HEIGHT IN RESERVOIR NO. FOUR
C   HSM1=MEASURED M. E. K. HEIGHT IN RESERVOIR NO. ONE
C   HSM2=MEASURED M. E.K. HEIGHT IN RESERVOIR NO. TWO
C   DELTA=THE DIFFERENCE IN ALCOHOL HEIGHTS IN THE TWO STATIONS
C   DELTM=THE DIFFERENCE IN M.E.K. HEIGHTS IN THE TWO STATIONS
C   TILT1=THE VALUE OF THE TILT CALCULATED BY CONSIDERING ALCOHOL
C   AS FLUID A AND M.E.K. AS FLUID B
C   TILT2=THE VALUE OF THE TILT CALCULATED BY CONSIDERING M.E.K.
C   AS FLUID A AND ALCOHOL AS FLUID B

```

DIMENSION

```

C   DIMENSION ID(100), NRA4(100), NRA3(100), NSA3(100), NSA4(100),
C   1NRM1(100), NRM2(100), NSM1(100), NSM2(100), HSA3(100), HSA4(100),
C   2HSM1(100), HSM2(100), DELTA(100), DELTM(100), EC1(100), EC2(100),
C   3TILT1(100), TILT2(100), RA3(100), RA4(100), SA3(100),
C   4SA4(100), SM1(100), SM2(100), RM1(100), IM(100), RM2(100), IH(100),
C   5Y1(100), Y2(100), Y3(100), X(100)

```

INPUT OF BASIC PARAMETERS

```

C *****
C   BL=1000.0
C   N=4
C   ALPHA=-5.000699
C   ALPHM=-0.00122
C   HR1=8.890
C   HR2=8.890
C   HR3=8.890
C   HR4=8.890
C   LL=30000.
C   UL=90000.0

```

READING THE DATA FROM THE LOGGER

```

C *****
C   CALL ASSIGN(2, 'COUNTS.DAT')
C   READ(2,1000)(ID(K), IH(K), IM(K), NRM1(K), NRA4(K), NSM1(K),
C   1NSA4(K), NSA3(K), NSM2(K), NRA3(K), NRM2(K), K=1, N)
C   1000 FORMAT(F6.1,2X,F5.1,2X,F5.1,2X,F9.1,2X,F9.1,2X,F9.1,2X,
C   1F9.1,2X,F9.1,2X,F9.1,2X,F9.1,2X,F9.1)

```

WRITING THE HEADING

```

C *****

```

WRITE(6,2000)

2000 FORMAT(1H1,10X,'THIS PROGRAM IS TO CALCULATE THE VALUE OF TILT ',
1'FROM FREQUENCY COUNTS',30X,'A-R MANNAA',///)
WRITE(6,2100)

2100 FORMAT(10X,'LIST BELOW SHOWS THE DATA AS READ FROM THE DATA ',
1'LOGGER',///,10X,'DAY',4X,'HOUR',1X,'MINUTE',4X,'NRM1',4X,'NRA4',
26X,'NSM1',5X,'NSA4',5X,'NSA3',5X,'NSM2',7X,'NRA3',5X,'NRM2',//)

C * * * * *

C WRITING THE RAW DATA

C * * * * *

WRITE(6,2500)(ID(K),IH(K),IM(K),NRM1(K),NRA4(K),NSM1(K),
1NSA4(K),NSA3(K),NSM2(K),NRA3(K),NRM2(K),K=1,N)

2500 FORMAT(10X,F5.1,2X,F4.1,2X,F4.1,2X,F9.1,F9.1,F9.1,F9.1,
1F9.1,F9.1,F9.1,F9.1,/)
 WRITE(6,2550)

2550 FORMAT(1H1,10X,'LIST BELOW SHOWS THE COUNTS REARRANGED.',
11X,'THE COUNTS OF EACH FLUID ARE LISTED NEXT TO',
2' EACH OTHER.',///,10X,'DAY',4X,'HOUR',1X,'MINUTE',4X,
3'NRA3',4X,'NSA3',6X,'NRA4',5X,'NSA4',5X,'NRM1',5X,
4'NSM1',5X,'NRM2',5X,'NSM2',//)

WRITE(6,2500)(ID(K),IH(K),IM(K),NRA3(K),NSA3(K),NRA4(K),
1NSA4(K),NRM1(K),NSM1(K),NRM2(K),NSM2(K),K=1,N)
WRITE(6,2600)

2600 FORMAT(1H1,10X,'LIST BELOW SHOWS THE VALUES OF FLUID HEIGHTS IN CM
1 INCLUDING ERRORS DUE TO THE TEMPERATURE EFFECT ON DENSITY ',///,10
2X,'D.Y',7X,'HOUR',4X,'MINUTE',9X,'NSA3',18X,'NSA4',18X,'NSM1',18X,
3'NSM2',//)

C * * * * *

C TESTING LOWER AND UPPER BOUNDS OF THE COUNTS

C * * * * *

DO 800 K=1,N

RA3(K)=NRA3(K)

RA4(K)=NRA4(K)

SA3(K)=NSA3(K)

SA4(K)=NSA4(K)

SM1(K)=NSM1(K)

SM2(K)=NSM2(K)

RM1(K)=NRM1(K)

RM2(K)=NRM2(K)

IF(NSA3(K)-LL)800,200,200

200 IF(NSA4(K)-LL)800,250,250

250 IF(NSM1(K)-LL)800,300,300

300 IF(NSM2(K)-LL)800,350,350

350 IF(SA3(K)-UL)400,400,800

400 IF(SA4(K)-UL)450,450,800

450 IF(SM1(K)-UL)500,500,800

500 IF(SM2(K)-UL)550,550,800

C * * * * *

C CORRECTING THE VALUES OF THE COUNTS

C * * * * *

550 RA3(K)=RA3(K)*(3.996/4.0)

RA4(K)=RA4(K)*(3.996/4.0)

SA3(K)=SA3(K)*(3.996/4.0)

SA4(K)=SA4(K)*(3.996/4.0)

RM1(K)=RM1(K)*(3.996/4.0)

RM2(K)=RM2(K)*(3.996/4.0)

SM1(K)=SM1(K)*(3.996/4.0)

SM2(K)=SM2(K)*(3.996/4.0)

C*****
C CALCULATING FLUIDS HEIGHTS

C*****
HSA3(K)=(RA3(K)/SA3(K))*HR3
HSA4(K)=(RA4(K)/SA4(K))*HR4
HSM1(K)=(RM1(K)/SM1(K))*HR1
HSM2(K)=(RM2(K)/SM2(K))*HR2

C*****
C WRITING THE HEIGHTS OF THE FLUIDS

C*****
WRITE(6,3000)ID(K),IH(K),IM(K),HSA3(K),HSA4(K),HSM1(K),HSM2(K)
3000 FORMAT(10X,3(F6.1,2X),2X,4(F12.8,10X),/)
800 CONTINUE
WRITE(6,3500)
3500 FORMAT(1H1,10X,'LIST BELOW SHOWS THE VALUES OF THE DIFFERENCES IN
1THE FLUIDS HEIGHTS IN THE TWO STATIONS IN CM AND THE VALUE OF THE
2 TILT',/,11X,'DAY',7X,'HOUR',3X,'MINUTE',4X,'DELTA',10X,
3'DELTAM',10X,'EC1',12X,'EC2',12X,'TILT1',11X,'TILT2',/)

C*****
C CALCULATING THE TILT

C*****
DO 900 K=1,N
DELTA(K)=HSA4(K)-HSA3(K)
DELTAM(K)=HSM2(K)-HSM1(K)
EC2(K)=(DELTAM(K)-(ALPHM/(ALPHA-ALPHM))*(DELTA(K)-DELTAM(K)))
EC1(K)=(DELTA(K)-(ALPHA/(ALPHM-ALPHA))*(DELTAM(K)-DELTA(K)))
TILT2(K)=ABS(EC2(K))/BL
TILT1(K)=ABS(EC1(K))/BL
X(K)=FLOAT(K)
Y1(K)=EC1(K)
Y2(K)=DELTA(K)
Y3(K)=DELTAM(K)

C*****
C WRITING THE VALUE OF THE TILT

C*****
WRITE(6,5000)ID(K),IH(K),IM(K),DELTA(K),DELTAM(K),EC1(K),EC2(K),
1TILT1(K),TILT2(K)
5000 FORMAT(10X,3(F6.1,2X),6(F11.8,4X),/)
900 CONTINUE
CLOSE(UNIT=6,DISPOSE='PRINT')
STOP
END

2 - Data From the Logger

THIS PROGRAM IS TO CALCULATE THE VALUE OF TILT FROM FREQUENCY COUNTS

LIST BELOW SHOWS THE DATA AS READ FROM THE DATA LOGGER

DAY	HOUR	MINUTE	HRM1	HRA4	NSM1	NSA4	NSA3	NSM2	HRA3	HRM2
30.0	12.0	47.0	81794.0	82692.0	55551.0	59332.0	54552.0	61319.0	84589.0	79845.0
30.0	12.0	48.0	82103.0	82688.0	55983.0	59354.0	54594.0	61301.0	84579.0	79841.0
30.0	12.0	50.0	82091.0	82683.0	60286.0	59349.0	54031.0	61293.0	84566.0	79834.0
30.0	12.0	52.0	82024.0	82676.0	56099.0	59345.0	54609.0	61288.0	84543.0	79826.0